Memo

To:	Bradley Waldrop, Steve Hiatt, Nolte & Assoc.
From:	Christine Welch, Brett Whitford, Kleinfelder, Inc.
Project:	30-1307-10.016
Date:	January 17, 2001
Re:	Vibration Impacts On Planned Trench Construction Reno Rail Corridor, Reno, Nevada

PURPOSE OF ANALYSIS & SCOPE OF WORK:

This report summarizes the computed displacements of the trench walls and track section. The displacements analyzed would result from of the construction of a 40 foot deep trench for slurry diaphragm wall construction which will be located as near as 16-feet from the edge of a rail road line in Reno, Nevada. A Finite Difference Model was setup for the Reno Rail Road Trench Stability project to evaluate the stability of the trench constructed through Reno along the railroad track under static loads. We also studied the stability of the trench when subjected to railcar-induced ground vibrations. Displacement vectors were analyzed at the end of both the application of typical train loads and rail car vibrations. Displacement histories were also analyzed along the trench walls and beneath the track.

FLAC - PROGRAM DESCRIPTION

Fast Lagrangian Analysis of Continua, (FLAC) is a two-dimensional explicit finite difference program for engineering mechanics computation. FLAC was primarily developed for geotechnical and mining engineers. FLAC offers a wide range of capabilities to solve complex problems in soil mechanics. Each element behaves according to the prescribed linear or non-linear behavior. The program allows the user to simulate the behavior of soil or other materials that may undergo plastic flow when their plastic limits are reached. Materials are represented by elements within a grid that is adjusted by the user to fit the shape of the soil structure to be modeled. The grid can deform in large strain mode and move with the material that is represented.

FLAC also contains a powerful built in programming language FISH. Fish offers unique capability to tailor analysis to meet specific needs, which may include implementing other constitutive models (which are not defined in FLAC). FISH subroutines will be used throughout the data files to simplify and automate necessary changes in the model size, material parameters slope geometry, mesh discretization and to perform parametric sensitivity analysis.

FLAC Evaluations

The following cases were evaluated

> Static stability of the trench for the case of staged excavation of a 40-foot deep trench in 10-foot increments. He model was allowed to reach equilibrium conditions at excavation stages of 10, 20 30 and 40 feet in depth.

> Two model meshes were created and run: a coarser mesh consisting of 960 zones and a very fine mesh consisting of 21600 zones.

> One input motion was analyzed that was provided by Harris Miller and Associates (HMMH). The data selected for the model were obtained by HMMH on the sidewalk near the track at the Sierra Street grade crossing. This data set was selected for the model because it showed some of the strongest vibrations of all those taken by HMMH. Vibration was applied as a velocity history in both coarse and fine meshes. This velocity history was applied along different lengths as a parametric study.

- Other cases were also analyzed during the initial model setup Phase. On completing these analyses, some were eliminated from subsequent evaluation.

Soil Properties

Soil properties used in the analysis were the following:

⇒ Soil Moist Density, γ_m=125.0-pcf
⇒ Soil Internal Angle of Friction, ϕ=38-degrees
⇒ Soil Cohesion, c=100-psf
⇒ Modulus of Elasticity, E=1.5E6-psf
⇒ Poisson's Ratio, μ=0.25
⇒ Slurry Density, γ_s=70.0-pcf

Laboratory triaxial strength tests for the project showed ϕ values of 38 and 39 degrees for the soil matrix tested. It should be noted that the actual values of ϕ for the entire soil/rock matrix would likely average over 42, and maybe as much as 45 degrees.

Model Setup

A staged analysis of the Reno Rail Road project was carried out to simulate the behavior of the track and the trench for both static and vibration cases.

DEVELOPMENT OF STATIC CONDITIONS

Figure 1 shows the coarse model mesh for the project. Once the model was created an applied pressure command was used to simulate the weight of the rail cars. This was input to be 3000-psf acting over a width of 8 feet in the 2-dimensional models, which exceeds the distributed loads for Cooper E 80 loadings. The boundary conditions specified for the problem were fixed in the x-direction for the left and right lateral boundaries and fixed in the y-direction for the bottom boundary. The top 5 feet of both sides of trench walls were fixed in the x-direction to model the installation of a shoring system. A groundwater table was set at 20-feet below the ground surface in the model.

After the model was allowed to reach equilibrium due to initial gravity stresses a 10-foot excavation was made at a distance of 16-feet from the edge of the railcar pressure. Simultaneously an equivalent fluid pressure of 70-pcf was applied all around the 10-foot excavation to simulate the effect of bentonite slurry, which is proposed to be backfilled in the trench to maintain stability. This condition was solved for and displacement histories were continuously recorded for the duration of the run.

This excavation and bentonite backfill operation was repeated in 3 more stages for the 20, 30, and 40-foot excavation cases. Displacement histories, x and y-displacement contours were recorded below the track, and along side the near face of the trench wall, and these are provided in the figures. The coarse and fine mesh were both run for the project and no significant differences were observed in the model behavior in terms of static displacements.

INPUT EARTHQUAKE TIME HISTORY

To study the effect of vibrations due to rail car movement on the trench stability a recorded acceleration time history was used. The time history obtained from HMMH was the file name Tape 1-29b.txt. This was an actual vertical motion acceleration time history that was recorded on a digital tape at a distance of 25 feet from a railroad track. The accelerometer was placed on stakes that were driven into the ground. The complete record was about 2 minutes long and an 18-second excerpt representing the larger amplitude of motions was provided to us by HMMH. This input acceleration time history was twice differentiated and a baseline correction was applied to the resulting displacement time history. This operation had to be performed since the excerpted-recorded motion contained a residual non-zero displacement at the end to shaking.

This corrected displacement was then integrated and the resulting velocity history was applied at the top of the FLAC model at the soil grid 8-foot wide track tie-ballast section at a distance of 16-feet from the trench (20.4 feet from track centerline to west edge of

trench wall). As a parametric study the input motion was applied to the surface up to 2-feet away from the trench and the results showed no significant increase in horizontal or vertical displacements. The velocity time history was applied to both the coarse and fine mesh and the resulting displacement vectors and histories showed no significant differences between coarse and fine mesh. Since the differences were insignificant all subsequent parametric studies and model results were derived from the coarse mesh. The coarse mesh also took about 5% of the time to execute as compared to the finer mesh, thus saving time and money.

RAYLEIGH DAMPING

Damping is due, in part, to energy loss as a result of internal friction in the intact material and slippage along interfaces. The effect of damping is a reduction of energy of the input motion, and damping could be material and mass damping, and includes the soil and structure in our FLAC model. In time-domain programs, Rayleigh damping is commonly used to provide damping that is approximately frequency independent over a restricted range of frequencies. Both mass and stiffness proportional damping constants were prescribed in the FLAC dynamic analysis. The Mohr-Coulomb constitutive model used produces hysteretic damping at large shear strains or when the yield strains are exceeded. However, the model does not produce material damping at small strains. To provide damping for small strains and eliminate reflection small reflections of wave at imperfect lateral boundaries, a small amount of Rayleigh damping equal to 0.0 was specified at a frequency of 45-hertz for all the models.

The frequency-dependent stiffness proportional damping was selected such that it matched well with the range of predominant frequencies response of the model. To estimate the range of predominant frequencies, the velocity response was recorded at the crest of the embankment. Fourier Transformation of this velocity at the top of the model using an un-damped analysis produced a velocity spectrum, which shows that the dominant frequency of the soil structure response is about 45-Hz. The range of dominant frequencies is a combination of input frequencies and the natural modes of the system. This run was performed with the structural elements and pore pressure generation model using the Imperial Valley Record. Based on the input response spectrum, most of the energy in the dynamic loading is contained between 30 to 50 Hz. A grid size was selected for both the foundation dense sands we had at least 8 to 10 zones per wavelength. This criterion for mesh descretization ensures sufficient points so that the waveform shapes can be modeled with sufficient accuracy. Free field boundary conditions were used along the right and left boundaries and a quiet boundary was applied along the bottom on the model.

SUMMARY OF RESULTS AND CONCLUSIONS

FLAC analysis was conducted to estimate the displacements of the track and the trench walls under simulated static and vibration train loading as a result of the construction of a 40-foot deep trench. The analysis indicates the track settlements due to static and vibration induced loads are less than 0.5". The lateral movement of the trench wall is also computed to be less

than 0.4″. The following section provides an explanation of the results, which are shown in Figures 1 to 8.

EXPLANATION OF FIGURES

Figure #	Title	Description & Discussion
1	FLAC Grid and applied Loads	Shows the mesh descertization and the loads applied along the trench walls representing the bentonite slurry pressure on the trench walls and the pressure from the track on the underlying soil. Loads are applied at the nodal points to represent pressure distribution, and are related to grid spacing.
2	Displacement Vectors for Static Train Load	The resulting displacement vectors shown in feet once the train load is applied and the 40-foot excavation has been completed. These displacement vectors represent the total cumulative displacements expected once the site is reached equilibrium. The maximum expected displacement is about 0.5″. It should be noted these displacements are greatly exaggerated for illustration purposes.
3	X-Displacement contours - Static Case	The resulting x-displacement contours shown in feet once the train load is applied and the 40-foot excavation has been completed. The maximum x-displacement is 0.3-inches at the trench wall.
4	Y-Displacement contours - Static Case	The resulting y-displacement contours shown in feet once the train load is applied and the 40-foot excavation has been completed. The maximum y-displacement is 0.4-inches beneath the track.
5	Y-Displacement History @Track bottom	The y-displacement beneath the track once the train load is applied and the 40-foot excavation has been completed. The maximum displacement is estimated to be 0.4-inches.
6	X-Displacement contours - Vibration Case	The resulting x-displacement contours shown in feet once the dynamic vibration loads have been applied. The maximum x-displacement is less than 0.01-inches.
7	Y-Displacement contours - Vibration Case	The resulting y-displacement contours shown in feet once the dynamic vibration loads have been applied. The maximum y-displacement is less than 0.01-inches.
8	Y-Displacement History @ Trench Wall	The x-displacement history along the trench walls during the application of dynamic vibration loads. The maximum displacement is estimated to be 0.01-inches.

Additionally, with respect to anticipated rebound of the train tracks, the amount of displacement shown resulting from the rail car loads is less than 0.4 inches, and occurs during the 40 foot excavation stage. Our analysis was performed to study the amount of movement resulting from the excavation. If the static train loads were removed and reapplied, simulating the repeated departure and arrival of trains, the resulting final displacement would not change, as a 100% rebound condition exists.

We understand that railroad standards for either Class2 or Class 3 allowable maximum rail differential and total offset are considerably higher, on the order of 3/4 to 3-inches,

than those movements which can be expected to result from the loads imposed on the slurry filled trench by train vibrations.

ACCURACY AND CONSERVATISM OF FLAC ANALYSIS RESULTS:

The computer program FLAC, Version 3.4, (ITASCA, 1999) was used in this analysis. The results of FLAC should be used as a guide in estimating the overall performance of the Railroad and trench system. In evaluating the FLAC results, one should keep in mind the program limitations, modeling assumptions and other uncertainties inherent in any nonlinear deformation analysis and in estimation of ground motion time histories.

The analysis assumed an infinitely long open trench, open for an indefinite amount of time. It is likely that the trench will be constructed in 20 to 30 foot section lengths, which will remain open for a short duration of time, typically of less than one day. Based on this fact, the model has some inherent conservatism built into it. Similarly, the acceleration time history record used for the study was one of the strongest records obtained from the site during the monitoring by HMMH, and so may be somewhat conservative for the "typical" vibration event.